

THE NEXT GENERATION OF SPACE TELEMETRY AND TELECOMMAND STANDARDS

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o OVERVIEW

A major work of the international Consultative Committee for Space Data Systems (CCSDS) has been the standardization of data exchange through the communications channels which interconnect remote spacecraft with their supporting ground systems. The present CCSDS Recommendations for Packet Telemetry, Telecommand and Advanced Orbiting Systems are in widespread use throughout the world space community and have already had significant impact on reducing mission operations costs. With their high performance coding schemes and packetization capabilities, the CCSDS Recommendations provide the necessary underpinning for the automated, error-free exchange of data between space and ground systems. However, their scope is mainly limited to basic data transfer; more sophisticated functions, such as the ability to aggregate both telecommand and telemetry data into recognizable files and transport them end-to-end through the space data network in a reliable and secure manner, are the subject of expensive project-unique design and labor-intensive operations.

An activity is now underway to emplace a "skinny stack" of upper layer space data communications protocols that will expand the current CCSDS telemetry and telecommand capabilities to provide a more comprehensive set of spacecraft data handling services which eliminate the need for project uniqueness. In the context of a joint project between the National Aeronautics and Space Administration (NASA) and the Department of Defense (DoD) in the United States, and the Defence Research Agency (DRA) in the United Kingdom, a set of draft specifications for the next generation of "Space Communications Protocol Standards" (SCPS) have been produced that cover the following technical areas:

- o an efficient file handling protocol (the SCPS File Protocol, or SCPS-FP), optimized towards the up-loading of spacecraft commands and software, and the downloading of files of observational telemetry data;
- o various flavors of underlying retransmission control protocol (the SCPS Transport Protocol, or SCPS-TP), optimized to provide reliable end-to-end delivery of spacecraft command and telemetry messages between computers that are communicating over a network containing one or more unreliable space data transmission paths;
- o an optional data protection mechanism (the SCPS Security Protocol, or SCPS-SP) which assures the end-to-end security and integrity of such message exchange;

- o a scalable networking protocol (the SCPS Network Protocol, or SCPS-NP) that supports both connectionless and connection oriented routing of these messages through networks containing space data links.

These four SCPS specifications are currently being presented to CCSDS with a proposal that they should be progressed towards full international standards. This paper reviews the proposed new capabilities and their impact on reducing the cost of designing and operating space missions.

1 CHANGING NEEDS

A dramatic change is occurring across many segments of the space community, driven by shrinking government budgets and new emphasis on developing commercial markets. Dimensions of the change include:

- o revolutionary advances in space microelectronics which will allow greatly increased intelligence and autonomy to be packaged into small spacecraft that can be deployed using inexpensive launch vehicles;
- o a shift towards decentralization in mission strategy, with movement away from "a few expensive spacecraft launched relatively infrequently" and towards "many affordable spacecraft launched relatively often";
- o a corresponding imperative to significantly reduce the costs of operating the increased numbers of spacecraft;
- o increasing reliance on cooperation (both national and international) to achieve complex space mission objectives in ways that are affordable to individual organizations, coupled with an erosion of the traditional boundaries between the civil, military and commercial space sectors, with emphasis on reducing wasteful duplication of effort and improving mission effectiveness by sharing infrastructure and capabilities.

This sea change in the space mission environment (which will occur between now and the end of the decade) virtually demands widespread standardization. Realizing missions launching in 2000 and beyond will be making design decisions in 1997, and recognizing that a good standard has a gestation time of at least two years, the standardization community has an extraordinary challenge on its hands to meet the coming needs. In the area of standards for space data communications and flight operations, we are fortunate to be able to build on the excellent foundations laid by CCSDS. The first wave of CCSDS Recommendations, which focus primarily on the data link interconnecting the spacecraft with its ground support system, introduced two sweeping new capabilities:

- o asynchronous packetized data transfer, which has unshackled the internal operations of spacecraft systems from being lock-stepped into the space/ground data communications process and has allowed adaptive telemetry and telecommand applications to evolve;
- o high performance channel coding, which has virtually eliminated the space link as a source of undetected bit errors and has thus made a

significant stride towards supporting true computer-to-computer data exchange between spacecraft and ground systems.

However, in spite of these advancements we are still a long way from spacecraft and their ground systems being able to conduct automated computer-to-computer dialog of the kind that is routinely supported on the Internet. In particular:

- a. The space link is only one component of the end-to-end data path between the user and a remote space investigation. There is currently no space-proven standard mechanism available to ensure that the end-to-end data transfer is fully reliable.
- b. As on board computers become increasingly capable and onboard storage shifts from tape recorders to solid state memories, more and more telecommand and telemetry applications will become file oriented. There is currently no space-proven standard mechanism available to support end-to-end file transfer.
- c. The current CCSDS telemetry and telecommand capabilities rely on relatively simple spacecraft configurations which have generally static routing relationships between end systems in space and on the ground. As space systems become more diverse (particularly as fleets or constellations of small spacecraft with in-space crosslinks emerge), there will be new requirements to route data dynamically through changing in-space network topologies. There is currently no space-proven standard mechanism available to efficiently support the various needed flavors of connectionless data routing.
- d. Space systems have traditionally tended to rely on their uniqueness to deter unauthorized access. As Internet connectivity becomes ubiquitous and space systems become more integrated with the global communications infrastructure, there will be an increasing danger of malicious intrusion or unauthorized access to sensitive information flowing within them. There is currently no space-proven standard mechanism available to ensure end-to-end space data protection.

Two things should be noted about this situation. The first is that most current missions are already wrestling with the problems of performing reliable, secure file transfers between space and ground, and are expending scarce resources either designing customized protocols or using the reasoning power of expensive human operators to provide the needed functions. The second is the "space-proven" aspect; there are certainly commercial networking protocols which can support these end-to-end capabilities, but they tend to be implemented to meet environmental requirements which are significantly different from those encountered in communicating with a remote spacecraft.

2 NEW PROTOCOL REQUIREMENTS

Budgetary pressures in the U.S. have forced a large scale re-thinking of the way in which space missions are executed. The space community is facing the hard fact that mission operations costs must be drastically reduced by eliminating labor-intensive manual activities and replacing them with highly automated systems. Planners in both NASA and DoD have come to realize the

important role that standardization plays in achieving significant cost reductions, particularly if the standards can be applied across a large market and the force attract the private sector to support them with a diverse set of commercial off the shelf (COTS) products.

Recognizing the significant size of the combined U.S. civil and military space market, NASA and the DoD formed the cooperative Space Communications Protocol Standards (SCPS) project in 1993 and conducted an exploratory study aimed at identifying the necessary characteristics of new dual-use upper layer space communications protocol standards. (Pursuing its own interests in interoperability for the future Skynet series of military satellites, the U.K. Defence Research Agency, DRA, later joined the project.) Using the familiar seven-layer Reference Model of Open Systems Interconnection (OSI) to frame the protocol architecture, and respecting the extensive installed base and widespread acceptance of the current CCSDS Data Link layer standards, it was decided to focus the study on the Network layer and above and to assume underlying CCSDS capabilities.

An iterative five stage process of requirements analysis was performed: first, a representative Set of upcoming developmental civil and military missions were surveyed to catalog their overall data handling requirements and to identify their constraints; second, a straw man Set of data communications services were defined that could support these requirements within the confines of the constraints; third, the services were analyzed to determine which were compatible with implementation via protocols; fourth, the services were scrubbed to determine those which were common to both civil and military systems, and to assign them to OSI layers; and finally the layered services were reality-checked against another set of candidate missions under development. The result (Figure 1) was a set of thirty needed capabilities which were distributed across four layers of protocol: ten in the Application layer; nine in the Transport layer; five in the Security sublayer; and six in the Network layer.

In parallel with defining mission needs in a top-down manner, a bottom-up analysis of the capabilities of various existing standard protocols at each of the layers was made. Since resources for new space-unique development were clearly going to be scarce, a policy of assuming the use of COTS-supported standards was adopted. For file handling, the Internet file transfer protocol (FTP), the ISO file transfer and access mechanism (FTAM) and the Space Station Freedom file protocol were examined. Within the Transport layer, the Internet TCP/UDP and the ISO TP4 were analyzed. Security features, located between Transport and Network, were mapped into the ISO and Internet Network layer security protocols (NLSP) and subsequent Layer 3 derivations of these protocols produced by the DoD. For the Network layer, the Internet Protocol (IP) and the ISO 8473 connectionless internetworking protocol were considered.

3 SELECTION OF NEW PROTOCOL APPROACHES

With both analyses completed, a tradeoff process was performed to select the baseline for the next phase, protocol development. It was here that the environmental factors associated with operating with one end of the communications network in space also had to be considered; spacecraft arc by

and large *not* just "another node. on the Internet". Space data communications protocol implementations [1111s(therefore recognize that:

- o Because of the cost and time involved with space qualification, on board computers and networks will inevitably lag their ground counterparts in capability. Program memory, processing speed and onboard communications capacity will continue to be primarily dedicated to control and data gathering applications; protocol implementations which hog these shared resources will not be viewed favorably by spacecraft designers.
- o Space/ground data communications channels are considerably different from the (primarily fiber-based) media used in terrestrial communications. Propagation delays are large or even huge; bandwidth is usually constrained (especially as spacecraft get smaller and their power generation capabilities and antenna apertures shrink) so protocol overhead is a serious issue; high error rates are sometimes encountered; the links may be interrupted by intermittent bursts of noise or mechanical obscurations; duplex communications are not always possible; large amounts of data must be exchanged during ground contacts with very low (e.g., 10%) duty cycles; and some long data sessions may have to span multiple ground station contacts.

In addition to answering the question "does this existing protocol provide the needed capabilities?", the selection tradeoff therefore also had to ask "is it compatible with a compact code size implementation and anticipated space-qualified CPU capabilities?" and "can it operate effectively over the unusual space/ground data communications link?". After a weighting and scoring process, including assessing code sizes and the maturity of the installed base, four protocol development approaches were selected:

- a. The Internet FTP was chosen as the basis for the SCPS File Protocol (SCPS-FTP). For space applications, commercial FTP needs extension to be able to: read and update individual file records (e. g., last-minute tweaking of parameters in a preprogrammed control sequence); allow the user to temporarily stop a file transfer so that it may be restarted later; allow a transfer to automatically resume after the underlying Transport service restores service following an interruption in space/ground data communications; support file and record integrity so that an interrupted file transfer or record update does not leave files in a potentially dangerous interim state; and to suppress the unnecessary overhead associated with regular FTP's ASCII reply codes. While preserving the FTP protocol architecture so that it can be interoperable with commercial FTP, the SCPS-FTP development adds these necessary capabilities and restructures the code so that it can be tailored to match various onboard processing and operating system limitations.
- b. The Internet TCP/UDP was selected as the basis for the SCPS Transport Protocol (SCPS-TP). For spacecraft applications, commercial TCP needs extension to be able to: assist on board applications by delimiting record boundaries (e. g., packets) instead of just delivering a byte-stream; provide a "best effort transport service" (BETS) so that a sender is not blocked indefinitely by unacknowledged data in the event of temporary outages on the space link; activate and refine an existing TCP option to allow window

scaling so that very large numbers of octets may be allowed to be "in transit" on high rate and/or long delay links; activate and refine an existing TCP option allowing timestamping [o support accurate determination of round trip time or sequence number extensions for very high rate (>100Mbps) users; permit the Transport checksum to be able to include the underlying SCPS Network Protocol address, as well as commercial IP; provide the capability to recognize data corruption and underlying link outage as valid causes of data loss (to augment the standard TCP assumption that all loss is caused by congestion), thus improving TCP performance over unreliable space links; activate and refine an existing TCP option to permit selective acknowledgement of out-of-sequence data, thus improving spacecraft buffer management; and to activate and refine an existing TCP option for header compression which reduces the size of TCP headers by replacing static information with a connection identifier, a necessary feature for bandwidth-constrained missions. Again, while preserving a protocol architecture that can be interoperable with commercial FTP, the SCPS-TP development adds capabilities and restructures the code so that it can be tailored to match the limitations of on board computers.

- c. A custom design was selected as the basis for the SCPS Security Protocol (SCPS-SP), the primary driver for defining a new protocol being bit efficiency. The SP is a very low overhead hybrid of the ISO NLSP, the Internet NLSP, the Internet Protocol version 6 (IPv6) security proposal and the Del's Security Protocol 3 (SP3). It supports various authentication, integrity, confidentiality and access control options for space data exchange without assuming the USC of any particular cryptography, algorithms or key management scheme.
- d. A custom design with a wide range of capabilities was selected as the basis for the SCPS Network Protocol (SCPS-NP), with the primary driver in rejecting commercial network protocols being the difficulty of providing the required space services with reasonable bit efficiency. The original goal of the NP was to provide an upgrade to the current connection-oriented CCSDS Path service to support connectionless routing through satellite constellations having dynamic topologies and the need for different routing treatments for different messages. However, during the protocol analysis the concept of *scalability* evolved, i.e., specialized capabilities are optional and missions with modest requirements are not penalized by having to carry the overhead baggage of unneeded capabilities. The resulting protocol supports selectable address sizing, selectable priority, various selectable addressing options that include point-to-point, multi cast and broadcast, and separate signaling of corruption and congestion. It can provide a minimum point-to-point capability with half the overhead of the current CCSDS Packet, a CCSDS "Path-like" configuration with equivalent overhead, and various modular expansions of capability and overhead all the way Up to "II" next generation" addressing.

The protocols may be deployed in several end-to-end data communications configurations, but will often support dialog between a ground operations center and the on board spacecraft data system (Figure 2). They may be stacked in various ways; for instance, the File and Security protocols are both optional and may be omitted. The Transport protocol may be carried within the new

Network protocol, or wrapped within current CCSDS Path service. In all cases, the existing underlying CCSDS capabilities are all preserved (though it should be noted that CCSDS is also separately studying the feasibility of a "next generation" of underlying standard space data link protocol). The effect of SCPS on top of current CCSDS is to support an Internet-like "full service" end-to-end communications dialog for space mission users, thus fostering widespread automation of space communications systems and consequent reduction in long-term mission operations costs.

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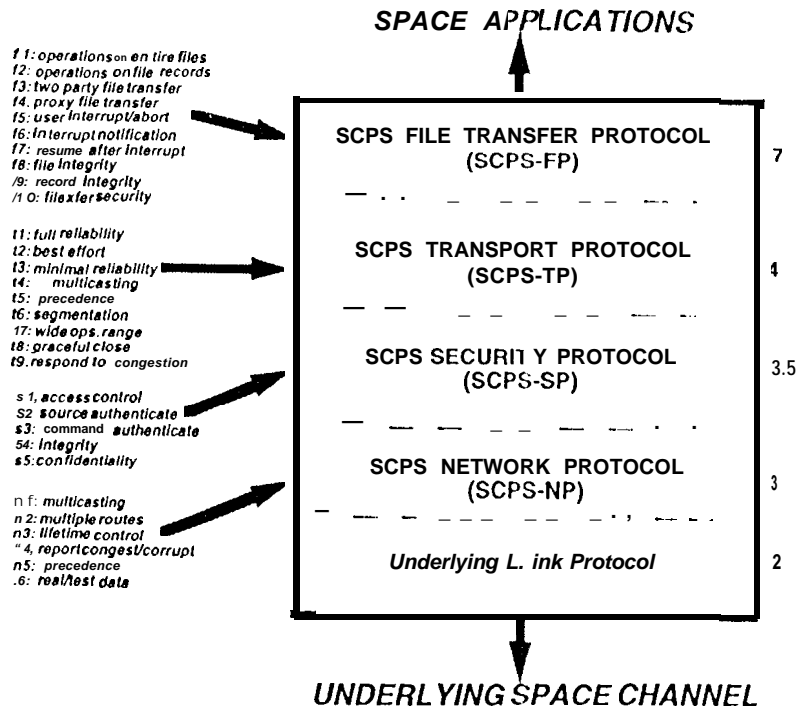


Figure-1: SCPS Protocol Architecture

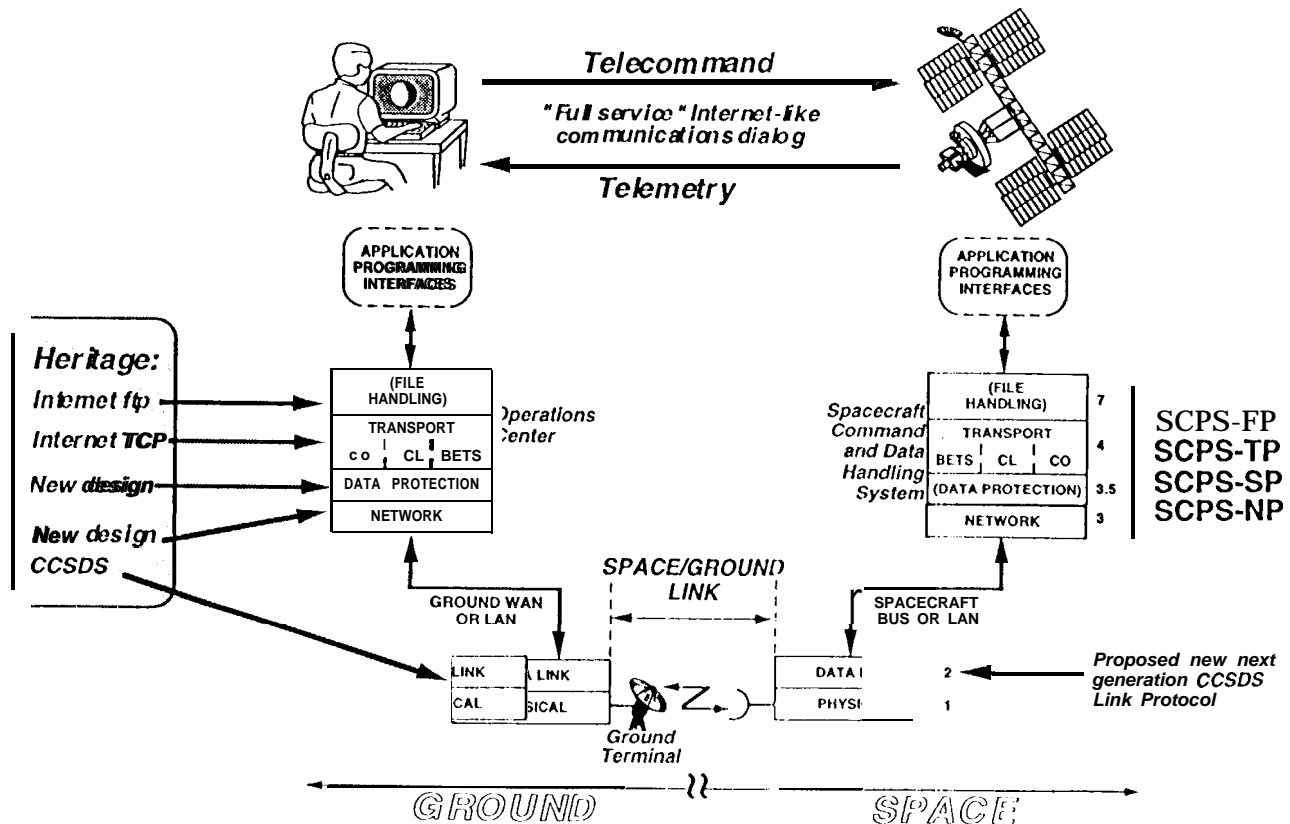


Figure-2: Deployed SCPS Stack